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Request for grant of a patent

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THE PATENT OFFICE
J
-5 FEB 2003
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1. Your reference — NANOPAT 6

2. Patent application numbe — 0302591.3 — -5 FEB 2003
   (The Patent Office will fill in tl

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*
   Dr DEREK ANTHONY EASTHAM
   58 VINCENT DRIVE
   CHESTER CH4 7RL

   Patents ADP number *(if you know it)* — 8403602800l

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — A NANO ACCELERATOR FOR FOCUSSED ELECTRON AND ION BEAM MACHINES

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   Patents ADP number *(if you know it)*

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*
0213772.7	15 JUNE 02
0219818.2	24 AUG. 02
0300265.6	7 JAN. 03

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

   NO

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

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Description 3

Claim(s) 2

Abstract 1

Drawing(s) 2 x 2

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*

Request for preliminary examination and search *(Patents Form 9/77)*

Request for substantive examination *(Patents Form 10/77)*

Any other documents *(please specify)*

11. I/~~We~~ request the grant of a patent on the basis of this application.

Signature: D A Eastham

Date: 4/2/03

12. Name and daytime telephone number of person to contact in the United Kingdom: Dr D A EASTHAM 01925 - 603581

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Fig.1

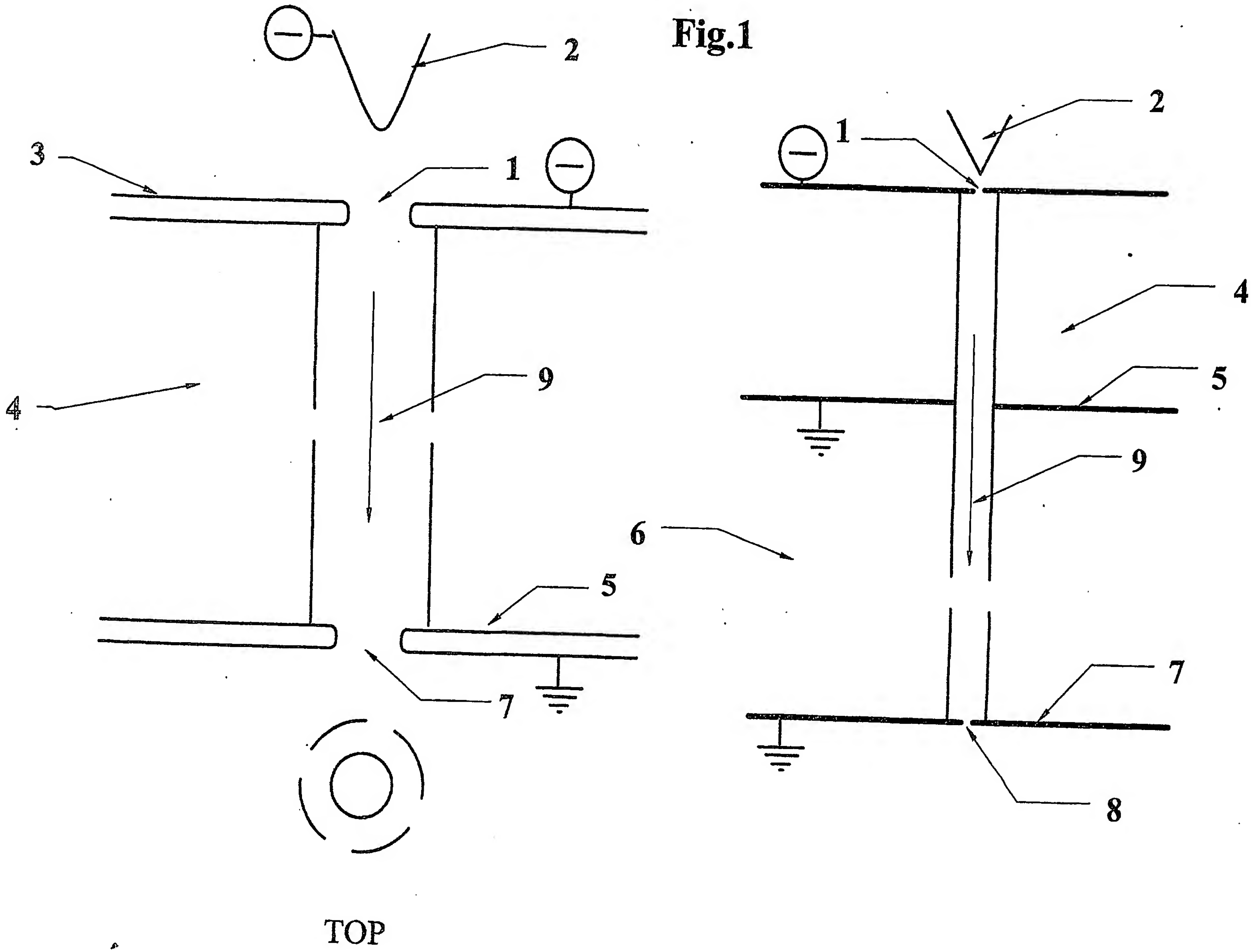
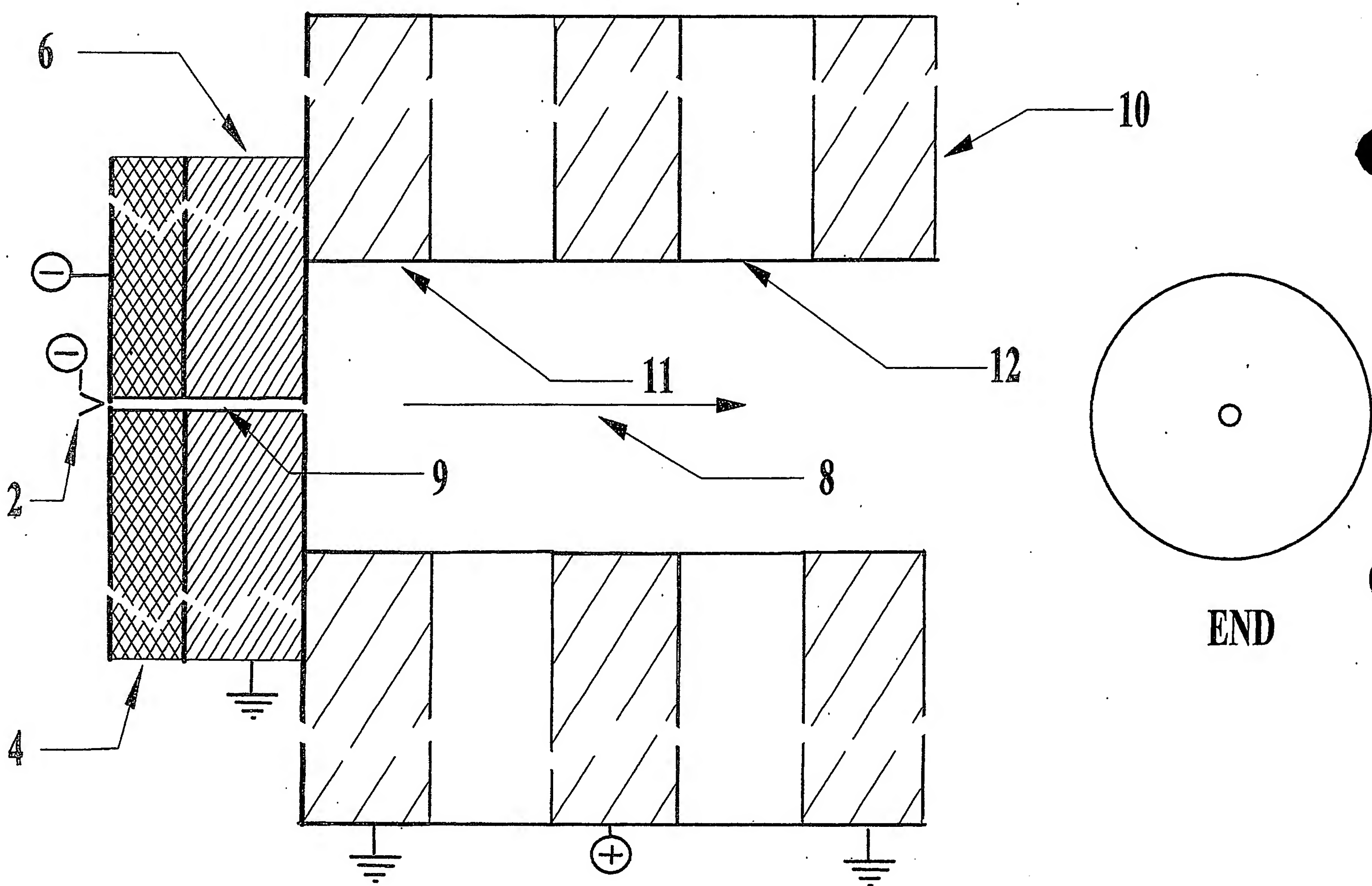


Fig.2



A Nanoaccelerator for Focussed Electron and Ion Beam Machines

In previous patent applications (0213772.7, 0219818.2 and 0300265.6) patents details of novel focussed electron and ion beam machines were described. These systems are essentially micro/nanoscale machines which are capable of focussing beams of electrons down to lateral sizes less than 1 nm and ions down to lateral sizes below 2 nm. The electron machine can be described in broad terms as a **scanning electron microscope 'on a chip'** and the ion machine as a **nano-milling machine 'on a chip'**. Both machines depend for their effectiveness on two step-change concepts. Firstly the beams from the machines are focussed in extremely short distances, less than 50μm from the final electrostatic lens, and secondly they employ nanosized accelerator sections in their design, which we call nanocolumns. These sections have three important functions. Firstly they can be used to collect most of the electrons from the field emitting nanotip if the electric field immediately after the entrance aperture is sufficiently high enough. Secondly these electrons can be focussed into a narrow beam, less than 50 nm diameter, which can be almost parallel. Lastly the accelerators can be used to support nanosized collimators. These are essential to eliminate scattering of electrons in the holes in the accelerating section.

In order to collect the electrons and focus them it is necessary for the accelerator to generate a high electric field along its length so as to produce a strong acceleration of the electron beam. In the previous patent an accelerating nanocolumn is constructed from a multilayer structure of alternate metal (conducting) and insulating layers through which is a hole of diameter less than 100 nm is fabricated and is the channel down which the electrons pass. By applying voltages to the conducting electrodes in this assembly it is possible to produce a high electric field along the evacuated aperture in the column. This present application describes a simpler method of producing nanocolumns or accelerators which have the same effect as the previous assembly. Furthermore this new method is simpler to manufacture and can accommodate the inclusion of restricting (anti-scatter) collimators at both ends of the column. The method is to manufacture the accelerator from a single sheet of high resistivity material through which holes are produced using microfabrication techniques. The favoured material, though not the only possibility, is single crystal doped silicon as used for the manufacture of microchips. The doping will normally be n-type (though p-type is possible) and the doping density should be such that the resistivity is in the range from1 kΩm-cm to 100 MΩm-cm but not exclusively. A

voltage applied across a thin film of such a material will ensure that there is a uniform electric field along any straight hole through the resistive material. The hole is made normal to the parallel sides of the thin wafer or film, which is the body of the accelerator and can be loosely termed a nanocolumn, in line with the previous terminology (0300265.6) for a column constructed from a multilayer of alternate insulating and conducting thin films. (Nanocolumn is used because the because the aperture through the film is in the nanometre size range.) In this circumstance the electric field is along the (evacuated) hole and it can thus accelerates electrons injected into the hole. A nanotip, which can be positioned above a hole of typical aperture 50 nm and at a distance of around 30 nm, will field emit electrons if the voltage on the tip exceeds that of the surface by about 10 volts. Both surfaces of the semiconductor are covered with a thin metallic film through which holes are manufactured concentric with the hole in the semiconductor. The diameter of the holes in the metallic film are smaller than that in the semiconductor so that these apertures act as anti-scatter collimators and can also be used to reduce the electron beam emittance. (The details of these nanocollimators and their method of manufacture are described in a separate patent application.)

.The operation of these nanocolumns in focussed electron and beam devices is as follows. A negative voltage is applied to the metallic layer nearest to the nanoprobe and larger negative voltage is applied to the nanotip. The metallic layer on the other semiconductor surface is at earth potential. By choosing these voltages correctly electrons emitted from the tip can be focussed and accelerated down the hole in the nanocolumn. An almost parallel beam of electrons with diameters less than 50 nm can be produced.

Figure 1 (LHS) shows the geometry of a column made from a doped silicon thin wafer or film. A thin film metallic layer, 3 and 5, covers the surfaces and has apertures (nanocollimators), 1 and 7, which are smaller than the hole in the semiconductor. The hole in the semiconductor might be typically around 50 nm with nanocollimators of 30 nm aperture. Electrons will be emitted from the nanotip, 2, if a sufficient voltage difference exists between the tip and the aperture. These will be accelerated and focused into an almost parallel beam if the voltage difference across the semiconductor is sufficiently large enough. (The arrow, 9, shows the electron beam direction in both parts of the figure.) Typically for an 0.5 μm silicon thin waver, or film, the voltage across the semiconductor might be around 300 volts and this will generate a uniform field along the hole of 600 MV/m. A longer nanocolumn is possible if it is made in two stages as the RHS of figure 1 shows. Here there are two layers separated by

separated by a conducting film, 5. The bottom layer, 6, is conducting and can be made from metal or preferably very low resistivity doped silicon. If the two metal films, 5 and 7, are at earth potential then the whole bottom column, 6, is also at earth potential. The nanoaperture, 1, performs the same function as in the LHS of the figure but the aperture, 8, which can be several microns from the nanotip is able to reduce scattering whilst further lowering the (phase space) emittance of the electron beam. The hole in this lower section of the system, 6, is fabricated at the same time as that of the upper accelerating section. Its sole function is to support the nanoaperture, 8, concentric with the hole in the semiconductor. A narrow electron beam, which is limited in diameter to the aperture size, 8, then passes to the electrostatic focussing elements of the microscope as shown in figure 2.

The complete microscope is shown in Fig. 2 with the hole in the nanocolumn, 9, and the nanotip, 2, being the source of electrons. The narrow beam of electrons, 8, passes from the nanocolumn and through the concentric einzel lens as shown. This lens is a simple three-element arrangement which is manufactured from conducting and insulating layers, 11 and 12, respectively through which a hole is manufactured. Multiple element lenses, containing five or more electrodes, are also possible to reduce aberrations as outlined in a previous application (0219818.2). The inside diameter (aperture of the lens) and spacing of the electrodes is chosen to give minimum aberrations and hence the smallest beam spot. Typical dimensions for the lens are about 2μm for the inside diameter and each layer being about 1μm thick. Manufacture of the einzel lens is simplified if it is made from a single thin waver of three distinct layers. Using silicon at different doping concentrations can produce a conducting layer, 11, and an insulating layer, 12. For a simple 3 element lens the outer two conducting electrodes are at earth potential and the central one is at the correct voltage to give a focus at the desired distance from the end of the assembly, 10. This whole assembly forms the body of the microscope and when this is fabricated at the edge of a stepped assembly as in the previous application (0300265.6) the microscope is essentially a single chip apart from the nanotip. However this nanotip is at the end of a cantilever so that it can be positioned on the centre of the nanocolumn entrance aperture and can thus be integrated into the nanochip to make a complete focussed electron (ion) beam machine, namely a '**Microscope on a Chip**'. Note that the resistive film from which the microscope body is made can have many holes in it so that they can all be accessed by moving the nanoprobe to any entrance aperture.

Claims

A nanoaccelerator which consists of multilayers of resistive thin films through which is fabricated hole (or holes), with diameters less than 500nm, and this can be used to accelerate and focus electrons from a field emitting nanotip. In this design the accelerating section is constructed from a material with a resistivity which allows a voltage of several hundred volts to be applied across the film without excessively large currents flowing in the material. The column has restricting apertures or collimators at each end to reduce scatter and define the beam direction and size. This arrangement allows one to produce an extremely bright electron sources suitable for use in electron microscopy. In the application considered here it is used in conjunction with a microscale einzel lens for scanning electron microscopy with Angstrom resolution.

There are many variations on the dimensions and the materials which will still preserve this original concept and its function. These are:

1) The preferred material for the nanocolumn is single crystal doped silicon but designs can employ amorphous and polycrystalline semiconductors of any species. The structure can be made from a combination of any conducting and resistive material. The essence of the invention is still preserved even if the accelerator section of the nanocolumn is made from intrinsic semiconductor or even an insulator.
2) The lower section of the nanocolumn can be made from any conducting material.
3) In general the optimum inside diameter for the nanocolumn hole is less than 100nm but diameters less than 10 μm will still have some efficacy as long as the collimators are included.
4) Collimator aperture sizes can range from 10 nm to 10 μm but the optimum size is around 30nm.
5) Gold is the preferred material for the metallic conducting films at each end of the whole nanocolumn but any conducting (metal) film is possible with thickness from 0.5nm to 100 nm.
6) The possibility of applying a very high frequency (RF) voltage across the nanocolumn in order to produce a pulsed electron beam is realistic. Because much higher voltages scan be applied in this condition the net result is a higher beam energy. Several

sections of similarly designed nanocolumn can be arranged in sequence so that much very high energies can be achieved in a compact accelerator.

7) The previous concept 6) also includes focussing sections to prevent the beam expanding and striking the column walls. These focussing elements are einzel lenses as described in this and previous applications.

Abstract

A Nanoaccelerator for Focussed Electron and Ion Beams

A nanosized accelerator for producing an almost parallel beam of electrons less than 50 nm is described. This consists of a nanosized hole in a semiconducting thin layer with collimators at both ends.

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